Bipolar Nickel Metal Hydride Battery

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Abstract

The Nickel Metal Hydride battery system has demonstrated its desirable power density, energy density, and life capabilities as an advanced battery for bikes, scooters, hybrid and all electric vehicles. However, battery cost is higher than desired thus limiting the full potential of this battery's use in the transportation sector.

Electro Energy, Inc. (EEI) is engaged in the development of a bipolar design for the nickel metal hydride battery system that offers performance advantages and cost reductions when compared to conventional cylindrical and prismatic designs. The EEI design is based on the use of individual sealed flat rectangular wafer cells that are stacked on top of each other to make a series connected battery. Each wafer cell contains one positive electrode, a separator material, one negative electrode, and outer faces that serve as positive and negative contacts of the cell and contain the cell's electrolyte. To construct a multi-cell battery identical cells are stacked with end contacts and end plates to fabricate a complete assembly.

For electric scooters and electric vehicles applications 500 Wh to 2 kWh modules are under development. Cost analysis of these modules in high-volume production show cost of materials of less than $200/kWh and a predicted selling price of approximately $300/kWh. Cells designed for hybrid electric vehicle applications contain 6 Ah capacity and have demonstrated over a thousand Watts/kg and up to 300,000 pulse cycles. *Copyright© 2002 EVS19*

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1. Introduction

The characteristics of available rechargeable batteries for hybrid electric, all electric, and single person transportation vehicles remains one of the limiting issues for the deployment of commercial quantities of these types of vehicles. The major characteristics which dictate the suitability of a given battery system are energy density per unit weight and volume, power density per unit weight and volume, cycle life and cost. The nickel metal hydride battery chemistry has emerged as a leading candidate to meet a number of these applications. The reactions that occur in this type of battery are as follows:

$$
\begin{array}{lcll}
 & & & E_o \\
Ni(OH)_2 + OH^- & \rightarrow & NiOOH + H_2O + e^- & .49 \\
M + H_2O + e^- & \rightarrow & MH + OH^- & .83 \\
\hline
Ni(OH)_2 + M & \rightarrow & NiOOH + MH & 1.32
\end{array}
\qquad (1)
$$

During charge the nickel electrode goes through two oxidation states of nickel nominally between the plus 2 and plus 3 valent states. During charge hydrogen is generated on the surface of the negative electrode and is stored within the electrode's hydride alloy structure. During discharge the hydrogen that is stored in the hydride alloy is electrochemically reacted and the nickel electrode is reduced. The theoretical energy density of the reactions based on a typical AB_5 hydride alloy of the $LaNi_5$ class which stores up to six hydrogens per molecule is 214 Wh/kg. In sealed cell operation oxygen is generated on the surface of the nickel electrode at the end of charge and during overcharge and is recombined on the surface of the hydride electrode. To achieve stable operation the rate of overcharge is limited to the recombination capabilities of the design to ensure that excessive pressure buildup does not occur in the cell, which can cause cell failure. The chemistry can also tolerate a limited degree of cell reversal, in a configuration in which the cell design is nickel limited. In reversal hydrogen generated on the surface of the nickel electrode is recombined by the opposing hydride electrode. Unique thermal characteristics of the nickel metal hydride chemistry are that during charge the hydrogen absorption reaction into the hydride electrode lattice is exothermic and the release of the hydrogen from the hydride electrode during discharge is endothermic. This results in the generation of modest amounts of heat during charge, which must be considered in the battery design to achieve a thermally stable battery configuration. However, the absorption of heat during discharge moderates thermal problems during high rate discharge.

The nickel metal hydride chemistry exhibits excellent high rate capability and long cycle life, which has resulted in its use for a number of portable electronic applications, hybrid electric, all electric and personal transportation applications. Batteries constructed to date have utilized conventional cylindrical coiled electrode and flat plate prismatic designs. These packaging approaches have evolved over many years and have been well developed for nickel cadmium and lead-acid type batteries. However, these packaging configurations add considerably to the resultant battery's weight, volume and cost when compared to the capabilities of the chemicals required for the reaction. In the battery field it has been well recognized that a bipolar type of construction in which electrodes are stacked in a pile with conductive partitions between cells would be preferred. This design is more compact, exhibits higher power capability, and would be lower in cost than conventional cylindrical and prismatic designs. However historic limitations of the edge seal of bipolar battery designs has limited its usefulness. Electro Energy, Inc. (EEI) has been concentrating on the development of a wafer cell bipolar design for the nickel metal hydride battery system that overcomes the historic cell edge seal problem and makes it a viable approach for producing batteries [1-6].

2. Bipolar Wafer Cell Design

Figure 1 shows a sketch of the EEI wafer cell design concept. Individual flat wafer cells are constructed with contact faces, one positive electrode, a separator, and one negative electrode. The contact faces serve to contain the cell and make contact to the positive and negative electrodes. The contact faces are sealed around the perimeter of the cell to contain the potassium hydroxide electrolyte. To fabricate multi-cell batteries, identical cells are stacked one on top of another so that the positive face of one cell makes contact with the negative face of the adjacent cell resulting in a series connection of the cells. To complete a full battery, current collecting contact sheets are placed on the end cells to serve as the positive and negative terminals of the battery and the entire stack is held in compression in an outer battery housing. By fabricating each individual wafer cell as a self-contained unit and sealing the perimeter of each cell, the design overcomes the historic problem of attempting to seal the edge of the multiple cells in a stack. The unit cells can be leak tested, electrically tested, and replaced if necessary to ensure the reliability of a full battery. This design requires an additional conductive layer between cells as opposed to conventional bipolar designs, which utilize one conductive partition between cells. This disadvantage is substantially overcome by the improved reliability of the edge seals of the single wafer cell concept. The EEI battery design has several advantages as summarized in Table 1.

Table 1: Advantages of EEI Nickel Hydride Wafer Bipolar Design

Each cell individually sealed	Allows repair or replacement of individual cells
No external cell terminals	No electrode current collectors
Adaptable to heat transfer fins placed in stack	Scaleable to large area, capacity, high voltage
Compatible with plastic bonded electrodes	Automated flexible manufacturing
Improved energy and power density	Lower cost

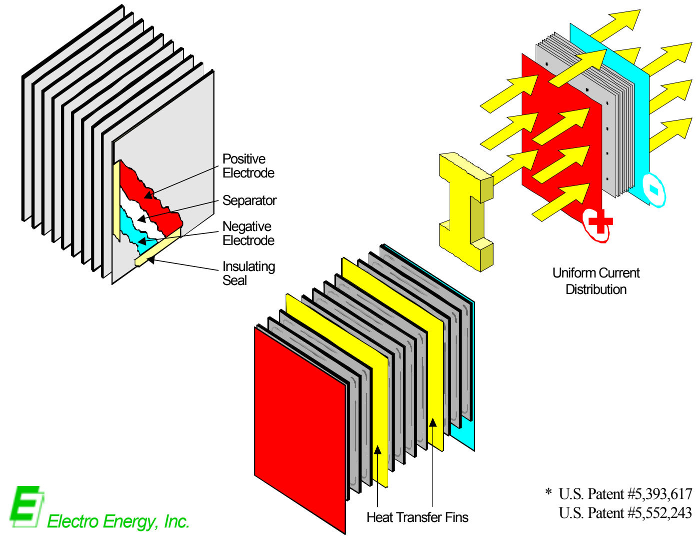

Figure 1: Schematic depiction of the wafer bipolar battery design

EEI has been pursuing a number of applications utilizing this design concept. The concept is very flexible enabling it to be configured with varying electrode thickness, electrode area and the number of cells in series fulfilling applications ranging from high energy to high power [7].

3. Energy Battery Configurations

For transportation applications requiring an energy battery, a basic cell of 20 Ah capacity utilizing an active electrode area of 6” by 12” has been developed. Figure 2 shows a layout of this cell, which has a typical weight of 325 grams and delivers 77 Wh/kg and 229 Wh/l at the cell level. Identical cells are stacked with ribbed end plates and end contacts in a battery housing to fabricate batteries. Figure 3 shows the layout of a 20-cell nominal 500 Wh configuration. Multiple cell and voltage configurations are under development utilizing the same basic cell as a building block. Table 2 presents the characteristics of these configurations. Since these designs utilize the same fixed end weights, the higher voltage stacks exhibit better energy density characteristics. Figure 4 shows a picture of a prototype of the 500 Wh unit. Figure 5 shows a photograph of the same type of unit with heat transfer fins along the long edges of the battery housing. This configuration adds approximately an inch to the width of the housing and 800 grams to the weight. This design is preferred when the battery is operated in such a manner that air-cooling is desired. The heat transfer characteristics of this battery design are excellent since the heat is transferred along the plane of the cells to the cell edges, which are contacted with thermal compound to the outer box sidewalls. Figure 6 shows the charging characteristics, voltage and temperature of the unit when subjected to a two-step charge format, four amps for five hours, and a topping charge of 0.5 Amps for 4 hours. Figure 7 shows the discharge characteristics of the unit at 5, 10, and 20 amps.

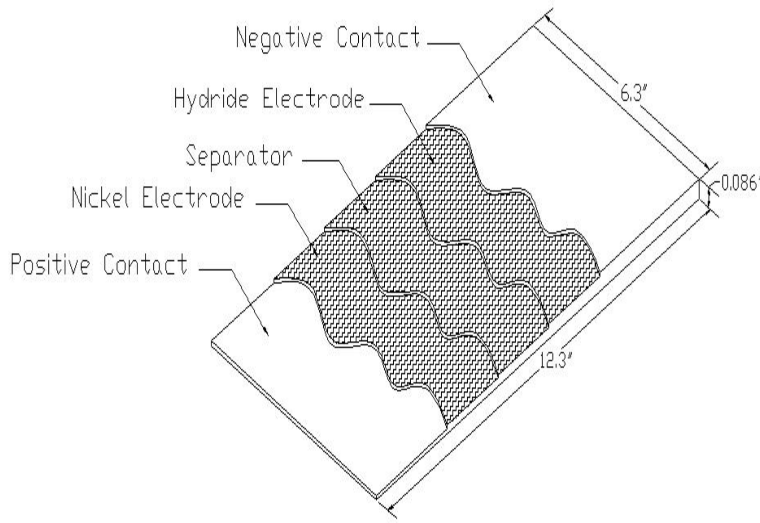

Figure 2: Typical cell layout

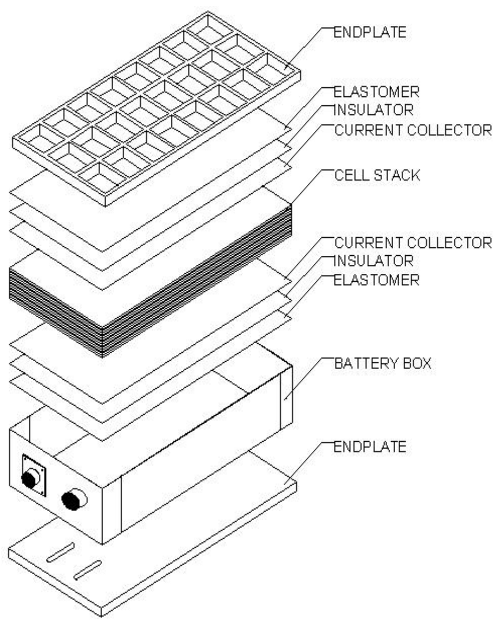

Figure 3: 20 Cell, 500 Wh Configuration

Table 2: 20 Ah Configurations

Nominal Voltage	Number of Cells	Energy (Wh)	Height (in)	Width (in)	Length (in)	Vol (in3)	Vol (l)	Weight (kg)	Wh/l	Wh/kg
24	20	500	3.00	6.4	12.7	244	4.00	8.0	125	62.5
36	30	750	3.86	6.4	12.7	314	5.15	11.4	146	65.8
48	40	1000	4.72	6.4	12.7	384	6.29	14.8	159	67.6
72	60*	1500	6.44	6.4	12.7	523	8.58	21.7	175	69.1
96	80*	2000	8.16	6.4	12.7	663	10.87	28.5	184	70.2

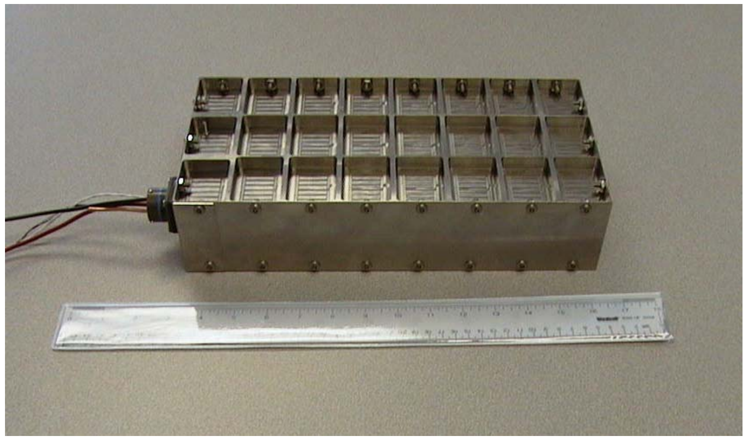

Figure 4: 24 Volt, 20 Ah Battery

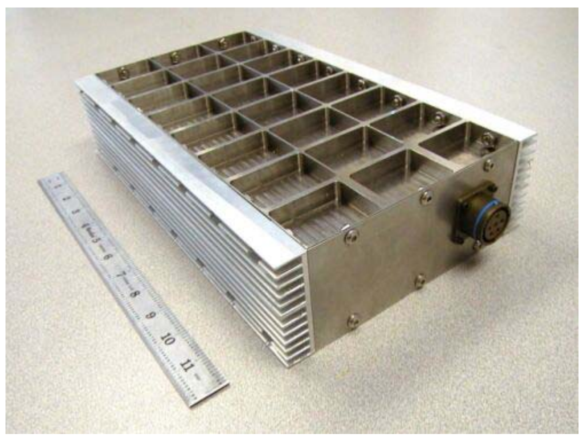

Figure 5: 24 Volt, 20 Ah Battery with heat transfer fins

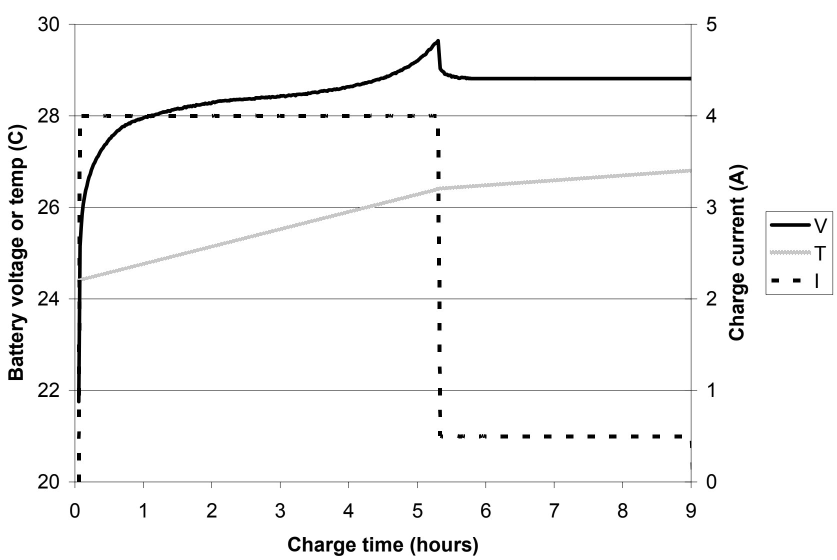

Figure 6: 500 Wh Module Charge Profile

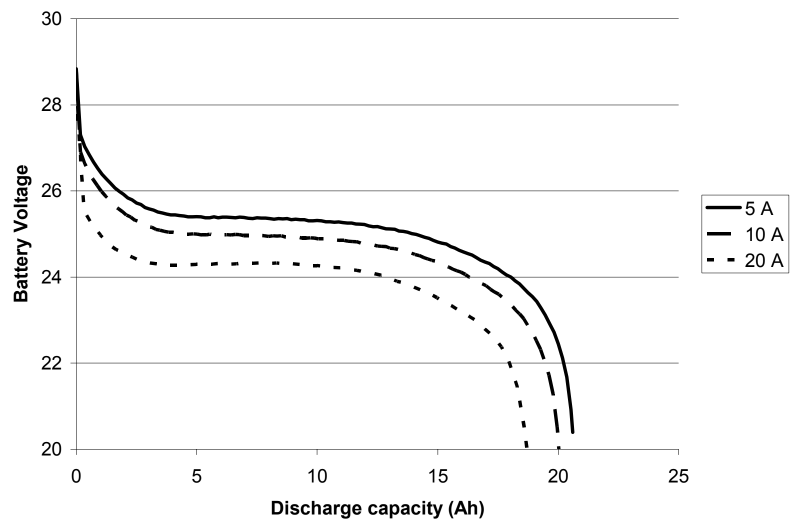

Figure 7: 500 Wh Module Discharge Characteristics

We are evaluating the 500 Wh units for a number of applications including electric scooters, electric bikes, wheelchairs, lawn mowers, etc. Figure 8 shows a photograph of the battery in an electric scooter that is typically supplied with two 12 volt, 12 Ah Lead-acid batteries under the floorboard. The EEI battery delivers over twice the range of the Lead-acid configuration and has better acceleration.

Figure 8: 24 Volt, 20 Ah batteries in electric scooter

4. Hybrid Power Battery Configuration

EEI has also been developing a battery for high power hybrid electric vehicle applications utilizing the same concept and design approach as described above [8]. A baseline cell of the same electrode area as described above for the 20 Ah cell with thinner electrodes normally rated at 6 Ah has undergone extensive testing. The applications studied is the battery requirements as defined by the USABC for hybrid electric vehicles. This requirement calls for a battery capable of 25 kW discharge power and 30 kW recharge power. The life target for this application has been set at 15 years, requiring 300,000, 25 Wh cycles when tested on a 72 second cycle profile as shown in Figure 9. The

EEI preliminary battery configuration selected to meet these requirements is a battery containing 280 of the 6 Ah cells. Extensive tests have been conducted at the single cell level to optimize electrode formulations and demonstrate the viability of this design approach. The 6 Ah cell was designed specifically for low impedance and high rate capability. Figure 10 shows the characteristics of the cell discharged at 80 amperes. Cells have been life tested for over 300,000 cycles. Figures 11 and 12 show the power and energy fade achieved with one generation of cell configuration life tested on the pulse profile shown in Figure 9. This indicates that the wafer cell design approach exhibits excellent power and life stability.

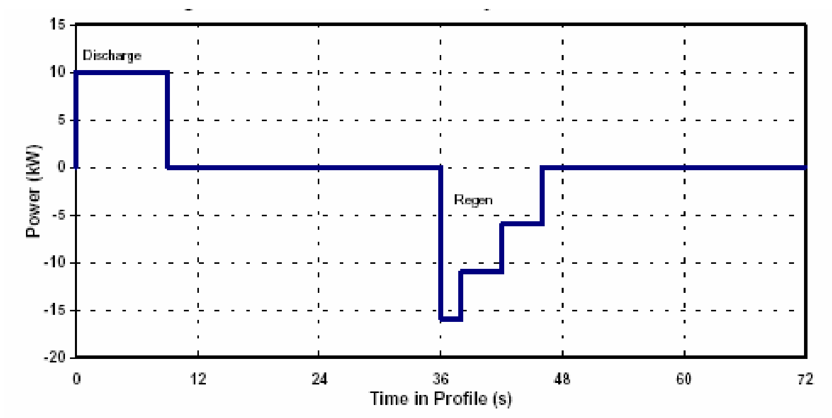

Figure 9. Power assist hybrid vehicle life cycle

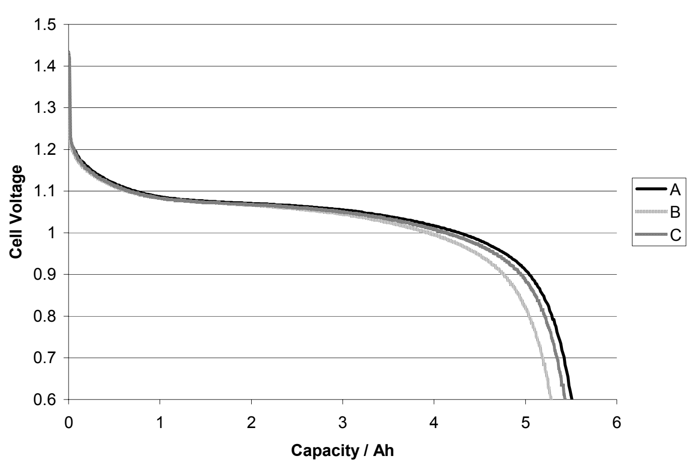

Figure 10. Discharge characteristics of 6 Ah cells at 80 amperes

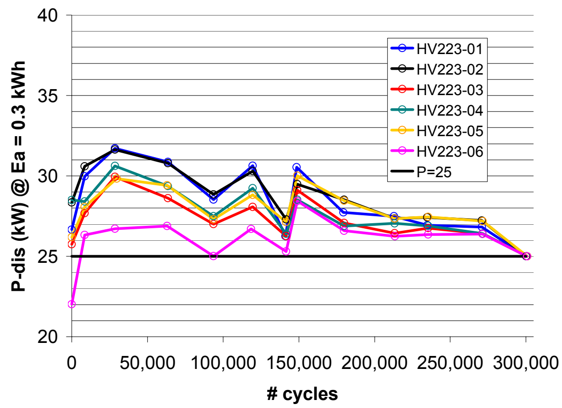

Figure 11. Power fade rate for 6 Ah cell series

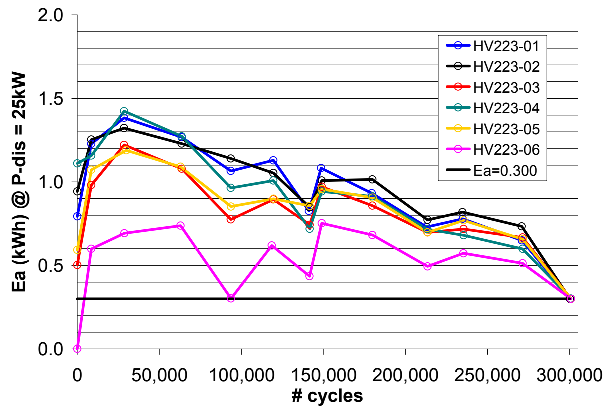

Figure 12. Energy fade rate for 6 Ah cell series

5. Cost

All of the applications described above are cost sensitive and one of the major advantages of the bipolar wafer cell design is the elimination of a number of cell components, the use of lower cost materials and simpler manufacturing techniques when compared to conventional cylindrical and prismatic designs. Manufacturing process development, cost analysis and cost reduction efforts are underway [9]. Table 3 presents an estimate of cost for the 1 kWh module as described in Table 2. Shown are the costs of active materials, other material, and packaging for a total of approximately $200/kWh. We estimate that in high-volume production based on a 1.5 multiplier of materials, the battery selling price will be approximately $300 per kWh. Subsequent design improvements and cost reductions should take 1 kWh modules to below $250/kWh.

Table 3: Cost Estimate (1000 Wh module)

	Quantity kg/kWh	Unit Cost $/kg	Total $/kWh
$Ni(OH)_2$ Active Material	3.8	9	34.20
Hydride Active Material	4.2	16	67.20
Other Cell Materials			66.00
Housing/Packaging			28.00
Total Materials Cost			195.40
Selling Price at 1.5 X Materials Cost			293.10

6. Conclusions

The Bipolar Nickel Metal Hydride wafer cell design overcomes leakage problems, which has been the historic barrier to the commercialization of bipolar battery configurations. The design has considerable flexibility to be customized for energy and power applications of varying voltage and capacity. For energy applications a family of modules ranging from 500 Wh to 2 kWh is being developed capable of delivering 62 to 70 Wh/kg and 125 to 184 Wh/l. It is anticipated with further development these energy density characteristics will be improved by approximately 10%. The cost estimate for the 1 kWh module in high-volume production is approximately $300 per kWh, with a future goal of below $250 per kWh.

Stable high power performance and exceptional life can be achieved by utilizing the same design concept with thinner electrodes. In excess of 300,000 short pulse cycles have been demonstrated for 6-ampere hour size cells. The attractive weight, volume, power, life and cost of the EEI bipolar design should make it a viable battery for many applications.

7. References

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[6] U.S. Patent No. 5,698,342, "Electrode Containing Coated Particle," issued 12-16-97.

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